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DEVELOPMENT OF A PROCESS CONTROL COMPUTER
DEVICE FOR THE ADAPTATION OF FLEXIBLE WIND
TUNNEL WALLS

Jürgen Barg

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Regeleinrichtung für die Adaptation von Flexiblen Windkanalwänden ."
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16. Abstract In wind tunnel tests, the problems arise of determining the wall pressure distribution, calculating the wall contour, and controlling adjustment of the walls. This report shows how these problems have been solved for the high speed wind tunnel of the Technical University of Berlin.			
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Development of a Process-Computer-Controlled Control
Device for the Adaptation of Flexible Wind Tunnel Walls

by

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Berlin, July 1980

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Symbols

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C_p	pressure coefficient
h	wall contour
i	run variable
l	length of the flexible wall
u	tangential component of the disturbance velocity
v	normal component of the disturbance velocity
x	coordinates
y	
DAC	digital information of the D/A-W
F	total calibration factor for displacement pickup
F_l	calibration factor of the D/A-W
H	wall contour, wall position
ΔH	difference of the should- and actual- wall position
I_M	motor current
M	Mach number
K	control factor
U	velocity (tangential), electrical voltage
V	adjustment speed of the adjusting member
α	angle of incidence
	integration intersection values
φ	angle of the transmission factor of the displacement pickup
ξ	integration variables
	velocity potential

Indices

a	initial value
c	computer
e	final value
m	measured
n	control step
o	offset
∞	free incident flow

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1. INTRODUCTION

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Because of the finite dimensions of a wind tunnel-test section the test results are falsified in model investigations. Adaptive flexible wind tunnel walls offer the potential to avoid to a large extent such false results. Beyond that a blockage of the test section can be avoided during transsonic flow. The principle of the adaptive walls has already been successfully tested in different research institutes [1,2,3,4]. These first tests made it clear that the time expenditures for control adjustments of the wind tunnel walls must be reduced if this principle is to be applied in commercially-used wind tunnels. For this a control device is necessary which can adjust the flexible walls in the shortest time possible. Here we find three problem areas:

- determination of the wall pressure distribution
- calculation of the wall contour
- controlled adjustment of the walls.

In the subject report we will show how these problems have been solved for the high-speed wind tunnel of the TU (Technical University) Berlin.

* Numbers in margin indicate pagination of original foreign text.

2. FUNDAMENTALS FOR THE DEVELOPMENT OF A CONTROL DEVICE

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2.1 Principle of the adaptive flexible walls

The principle of the adaptive flexible walls rests on the controlled adjustment of the walls to coincide with stream lines. If the walls take on the shape of those stream surfaces which appear at this place during unlimited flow around the model, then the flow around the model is free of wall interference. Here we first assume for the sake of simplicity frictionless flow.

Figure 1 shows a sketch of the flow field in which the walls were reshaped to streamline contours. Between the walls a real flow field is developed. One can imagine that this flow field is continued beyond the walls. In actuality this flow field does not exist; however, the assumption of a fictitious external flow field is necessary for the determination of the correct wall contour. Under the assumption that the wall represents a stream surface equal pressure must exist on both sides of the wall since a stream line can take on no forces. Therefore, for the adaptive wind tunnel we have

$$P_{\text{external}} = P_{\text{internal}}.$$

The internal pressure is measured, the external one can be calculated. It already becomes clear here that only the boundary values at the walls must be compared in order to obtain an adaptation of the walls.

The problem to determine the correct wall contour is solved iteratively: as an example, starting with a straight wall we first measured the internal pressure distribution. The external pressure distribution is constant because of the straight wall. Therefore we have

$$P_{\text{internal}} \neq P_{\text{external}} = \text{constant}.$$

The walls must now be deflected in such a way that the internal and

the external pressure distribution approach each other. For this two possibilities must principally be taken into consideration

- Turning of the wall through trial and error (evolution strategy)
- Calculation of a wall contour based on the measured internal pressure distribution.

While in the first case many iteration steps are generally necessary in order to obtain a streamline-type wall contour, this can be done in the 2. case by only a few iteration steps.

The following scheme seemed to be suitable:

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One forms a weighted average value between measured internal and calculated external pressure distribution and with it calculates a wall contour which would cause this pressure distribution in the fictitious external flow.

The average value can be calculated as follows:

$$C_{p_{estim_{n+1}}} = K \cdot c_{p_{internal_n}} + (1-K) \cdot C_{p_{external_n}} \quad (1)$$

with $C_{p_{estim_{n+1}}} = C_{p_{external_{n+1}}}$ and $0 < K < 1$

With this new estimated value the new wall contour can be calculated. The wall contour is then set as calculated and a renewed wall pressure measurement can follow. For a favorable selection of K it is possible to find an adaptive wall after two iteration steps.

New theoretical works of Lo [5] show that a calculation of the adaptive wall contour with only one iteration step is possible by the use of two measured flow quantities (u- and v-components) on a control surface.

2.2 Control algorithms

As suggested in the previous section the factor K denotes the convergence behavior of the iteration resp. control*. An analytical determination of an optimal factor K , also denoted in the following as control factor, is possible only for very simple flow cases; such as for Sears [6]. The problem here lies in the fact that the entire flow field must be capable of analytical solution internally and externally which, however, is limited to a few special cases.

Here we attempted in two ways to determine the control factor empirically:

- numerical simulation of the control with calculation of the internal- and external field (panel method, theory of small disturbances)
- experimental determination of the control factor.

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It is basically true that as the control factor K becomes larger, a weighting of the measured $C_{p_{\text{internal}}}$ -component takes place at the expense of the $C_{p_{\text{estimated}}}$ quantity. This can be interpreted as a larger back-coupling effect of the process quantity and, as a result, a smaller dampening resp. sensitivity increase of the entire control circuit.

Simulation on the computer

Before the first experimental investigations were made, the control process was simulated on a computer. The thus determined values for K were intended to furnish the basis for further investigations for the determination of suitable control factors.

For the simulation we had available, in addition to a program (EXTER)

* In the following we shall speak of control since the adaptive wind tunnel represents a back-coupled system.

for wall contour calculation, a program WINDKA which calculates the flow around a profile between two randomly shaped wind tunnel walls. It is based on the panel method and takes into account no viscous effects. Compressibility effects were taken into account by means of Krahm's transformation. The calculations were conducted for an NACA 0012-Profile for various angles of incidence. Here the ratios profile length to wind tunnel height resp. to wind tunnel length of the actual wind tunnel were used as a basis. As an example, the controlled process for a control factor $K = 0.5$ and $K = 0.35$ is plotted in both figures, figure 2 and figure 3 for an $\alpha = 0^\circ$. It is shown that in general large control factors ($K \approx 0.5$) bring about a periodic, while small one ($K \approx 0.25$) bring about a monotone adaptation. It was found that $K = 0.35$ was a favorable value for the angle of incidence range from 0° to 10° . It is remarkable that 2-3 control steps were sufficient to obtain an adaptive wall shape.

Experimental_determination

The experimental investigations were made within the framework of a larger test series with an NACA 0012-Profile. Here it was shown that control factors in the range $0.25 \leq K \leq 0.35$ produced a fast adaptation (2 - 3 control steps). Detailed information can be found in [7].

The optimal control factors found in the experimental investigations are somewhat smaller than those determined during the numerical simulation. This differing result must be attributed primarily to the following facts: /8
Compared to the calculated wind tunnel flow (program WINDKA) the actual wind tunnel flow is relatively sensitive toward changes of the wall contour, especially in the transsonic range. This effect is shown clearly in the pressure distributions along the wall. A compensation of the greater sensitivity is attained by a smaller control factor.

An additional reason for the deviation of the control factors from the two mentioned methods rests in the fact that the program WINDKA does not take into account friction effects.

2.3 Theory for calculation of the external field

The calculation of the external field makes possible the determination of the wall contour based on the pressure distribution obtained with the aid of control algorithm. This calculation represents, in contrast to the generally conventional calculations in aerodynamics, an inverse computer method; it is designated as a design method. A solution for the design method is possible through the linearized potential equation [8] which opens up the possibility of relatively short computer time.

Starting with the linearized potential equation $(1 - M_\infty^2) \phi_{xx} + \phi_{yy} = 0$ we obtain in the velocity components on the chord ($y = 0$) a weakly curved wall contour $y_n = h(x)$;

$$u(x,0) = u_\infty \left(1 + \frac{1}{\pi} \int_0^1 \frac{dh}{d\xi} \frac{d\xi}{x-\xi} \right)$$

$$v(x) = \frac{dh}{dx} u_\infty$$

In order to determine the wall contour $h(x)$ resp. the slope $\frac{dh}{dx}$, the above equation must be interpreted as an integral equation. The solution was provided by Betz and Fuchs-Hopf as

$$\frac{dh}{dx} = -\frac{1}{\pi} \int_0^1 \frac{u(\xi)}{u_\infty} \sqrt{\frac{\xi(1-\xi)}{x(1-x)}} \frac{d\xi}{x-\xi} \quad (2)$$

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whereby u/U_∞ denotes the disturbance velocity distribution on the chord. Between this disturbance velocity component and the pressure distribution there is here the relationship $C_p = -2 u/U_\infty$. Since for the wall deformations we are dealing here with small deflections, one can set the velocity on a "chord" equal to that on the wall surface.

Since equation 2 is to be used for a wind tunnel wall of length $l_e - l_a$, we must first make a coordinate transformation

with

$$\xi = \frac{\xi' - l_a}{l_e - l_a}, \quad x = \frac{x' - l_a}{l_e - l_a} \quad \text{und} \quad h = \frac{H}{l_e - l_a}$$

$$d\xi = \frac{d\xi'}{l_e - l_a}, \quad dx = \frac{dx'}{l_e - l_a}, \quad dh = \frac{dH}{l_e - l_a} \quad l = l_e - l_a$$

$$\frac{dH}{dx'} = -\frac{1}{\pi} \int_{\xi'=l_a}^{l_e} u \frac{(\xi' - l_a)}{U_\infty} \sqrt{\frac{(l_e - \xi')(\xi' - l_a)}{(x' - l_a)(l_e - x')}} \frac{1}{x' - \xi'} d\xi'$$

In order to take compressibility into account, one uses for

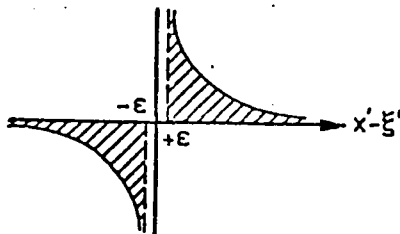
$$\frac{dH}{dx'} = \frac{dH_{\text{KOMP}}}{dx'} \cdot \frac{1}{\sqrt{1 - M_\infty^2}}$$

From this we obtain

$$\frac{dH_{\text{KOMP}}}{dx'} = -\frac{\sqrt{1 - M_\infty^2}}{\pi} \int_{\xi'=l_a}^{l_e} \frac{u(\xi' - l_a)}{U_\infty} \sqrt{\frac{(l_e - \xi')(\xi' - l_a)}{(x' - l_a)(l_e - x')}} \frac{1}{x' - \xi'} d\xi' \quad (3)$$

2.4 Numerical method

Based on equation 3 we developed the program EXTER which carries out the numerical integration according to Simpson's Rule. For the discontinuity at the location $\xi' = x'$ the Cauchy main value is also introduced:



The step width ϵ was determined empirically. For this we selected a flow case which allowed an exact calculation of the v-component resp. the wall contour. During the numerical solution the step width was reduced until the error between the exact and the numerically determined v-component took on an order of magnitude of about 0.1. Here we obtained for ϵ a value of 0.01.

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As length of the wind tunnel wall we used here the length of the flexible portion of the walls which for the wind tunnel described here is $5.5 \cdot l_{\text{profile}}$ with $l_{\text{profile}} = 10$ cm. The u-distribution is determined from 23 pressure measurements per wall. Intermediate values for the numerical integration are formed with the aid of a spline function. The calculated v-distribution and wall contour are also represented by 23 points. After an optimization of the program the calculation of the upper and lower wall shape acquires ca. 8 seconds. For this we must add the input and output times. (In-out-spooling, output to printer etc). of ca. 2 - 15 sec. The indicated times were measured on a Hewlett-Packard Computer with a central unit of type 2117F and Floating-Point Processor.

3. CONTROL DEVICE

3.1 Total buildup

In the following chapters we shall describe the electronic control device of the adaptive wind tunnel (figure 4). Since this device is composed primarily of computer resp. processors, no great meaning is attached to the software.

The block diagram in figure 5 presents an overview of the hardware buildup of the control device. The process computer constitutes the central unit. It coordinates the entire sequence of the control, carries out the data acquisition and calculation of the wall contour. A second computer (microprocessor-system) processes the wall contour data and releases them as analog values to the Servo-System which then adjusts the wall contour. Beyond that it controlled the motor current resp. torque in order to shut off the motors if these values are exceeded. With this device the walls are protected, on the one hand, from overloading, and on the other hand, the end of a readjustment phase is indicated.

3.2 Servo-System

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The Servo-System was constructed especially for the adjustment of the flexible walls. It consists of 2 x 8 individual Servo-Systems in accordance with the number of the positioning members. The requirement made of the entire system was, on the one hand, a fast adjustment of the walls, and on the other hand, an attempt was made to stress the flexible walls as little as possible during their adjustment.

No exact statements could be made as yet concerning the adjustment accuracy during the development of the control device. From a size standpoint an accuracy of 1/10 mm was certain since the thickness tolerance of the flexible walls exhibited about the same magnitude. The displacement pickups selected in this way attained a resolution of 0.08 mm for a linearity error of 0.2 % referenced to 50 mm available stroke so that an adjustment tolerance of a maximum of 0.18 mm was attained. During most of the tests it was shown that this accuracy can be considered as sufficient. However, in the transsonic Mach number range an increase in accuracy by a factor 2 would be desirable.

The wall adjustment speed is determined essentially by the motor size used. For mechanical reasons a motor with a power of

12 watt could be selected which allows a maximum adjustment speed of 1 mm/sec. However, this value is attained only for large differences between should- and actual positions. For smaller values an rpm regulation reduces the adjusting speed in order to avoid, on the one hand, travel beyond the should- position, and, on the other hand, to bring about a stress relief of the walls during the adjustment phase. Figure 6 shows the block diagram of the Servo-System. The should-value of the position is given out by the microprocessor as 12-bit information and is converted in the digital/analog-converter (D/A-W) into an analog signal. The input amplifier forms the difference between the should- and actual position*. In accordance with the characteristic line of the rpm regulator (figure 7) the latter produces an output voltage as a function of the difference voltage which is led via the power amplifier to the electromotor. Its rpm is nearly proportional to the voltage introduced.

The motor adjusts the positioning member by means of a spindle. /12 The instantaneous position is provided by a potentiometric displacement pickup. If the difference between the should- and the actual position is large, then the circuit produces the highest possible voltage which corresponds to the rated motor voltage. The adjusting speed then is ca. 1 mm/sec. If the difference is smaller, the motor voltage decreases and thus also the adjusting speed. If the difference $\Delta h_{\min.} = 0.045 \text{ mm}$, the smallest adjusting speed of ca. 0.25 mm/sec is obtained. Deviations smaller than ΔH_{\min} produce no motor voltage. If in this range the motor voltage abruptly drops to zero, then because of the lower output resistance of the power amplifier,

* The input amplifier is constructed as a sum amplifier; since should- and actual value voltages here have opposite signs, the difference is formed.

the rpm of the motor decreases greatly so that an overrun of the position is avoided.

The adjustment speed approximately follows the following function:

$$V_{st} = V_{min} + \frac{V_{max} - V_{min}}{\Delta H_{max} - \Delta H_{min}} \cdot \Delta H \quad (4) \quad \Delta H_{min} \leq \Delta H \leq \Delta H_{max}$$

Through this action it can become possible that, e.g., two position members which are required to adjust different path lengths, reached their should position at about the same time so that the required low wall stress during the adjustment phase is obtained.

The entire electronics of the Servo-System, their current supply, and the controlled network portion of the electromotors are housed in 19"-slide-in units (figure 8). Above it the microprocessor system is located. It consists of the CPU-board, memory board, and 2 boards with 8 D/A-W each.

3.3 Microprocessor-process computer-coupling

The Servo-System processes analog input values. Therefore the wall contour determined by the process computer must be converted to analog signals. First the digital wall positions are stored in a microprocessor and, coded appropriately, are paths to the D/A-W. The coupling of the two computers takes place on the process computer side via the process periphery* and on the microprocessor side via a parallel input/output interface with interruption possibility.

* Description of the process periphery (DEV systems 8.1 and 8.4) was also provided by the manufacturer.

Figure 9 shows the connection with the data flow direction. The data are transmitted in 8-bit blocks whereby two blocks must be transmitted for one position. A cycle signal from the process computer provides the synchronization. After each cycle output the microprocessor sends out a occupied-signal which is led to the process computer via the input card of the process periphery. The process computer waits until the signal is returned by the microprocessor (data have been processed) and then starts with a new output. Figure 10 shows the flow diagram.

3.4 Data acquisition device

The data acquisition device determines the wall- and profile pressure values. In addition it must take on the control of the scanivalves and the interrogation of the pressure pickups. Figure 11 shows the components of this device.

The DMS pressure pickups are supplied by the feed device with a highly accurate direct current voltage. It makes possible at the same time a displacement of the zero point. The direct current amplifiers amplify the low output voltage of the pressure pickups ($\pm 35 \text{ mV}/\pm 500 \text{ mbar}$) by a factor of 130. This voltage is sufficient in order to completely control the following A/D-W. Since the amplifiers possess an output with impressed current, a shunt resistance is necessary which produces a voltage decrease proportional to the current. In order to eliminate the line resistances between amplifier and analog/digital converter resp. multiplexer input, the shunt resistance was placed directly at the multiplexer inlet.

Since the pressure pickups were connected to a common feed voltage source, a galvanic separation of the pressure pickup was necessary on the output side. This device prevented mutual effects of the pressure pickup output signals and ground loops. The galvanic

separation is located between amplifier input and output.

The amplified pressure pickup signals lie in the channels 0 and 1 of the multiplexer. One channel is selected per software and the instantaneous value is stored in Sample and Hold. The value is retained during the conversion time (8 μ s) of the A/D-W. The digital information of the A/D-W is recalled by the data acquisition program and is processed further in it.

For the control of the scanivalves two signals are necessary: /14
step pulse and return pulse. The signals are generated via the software by setting resp. raising two output bits of the output card. From the short pulses the driver stage generates a 50 ms-long step pulse resp. a 2.5 sec-long return pulse. At the same time an amplification of the pulses takes place for driving the scanivalves (24 V/4 A).

4. SOFTWARE FOR THE CONTROL DEVICE

4.1 Sequence of the control

For the automation of the "adaptive wind tunnel" software was necessary for the process computer and for the microprocessor. While the programs of the process computer were written in FORTRAN, those for the microprocessor had to be written in Assembler. Since these programs communicate continuously with the process periphery, they had to take into account problems such as synchronization of the two computers, data coding, and interruption controls.

Figure 12 presents a summary of the sequence of the control:

The microprocessor can preselect an arbitrary initial wall contour which is then adjusted by the Servo-System. After that the programs initiated in the process computer can be started by pushing a

button. The incident flow Mach number is indicated in 0.5 sec cycles by a luminous diode display. A Mach number correction can be made manually. A continuation of the programs for the wall- and profile pressure distribution measurement can be started by another push button. This is followed by a interrogation to see if the control process is converging. At the time the judgment is still made by the service personnel. If no adaptation of the walls is achieved, a new wall contour is calculated and relayed to the microprocessor. This again causes the Servo-System to adjust the calculated wall contour. The process is repeated until an adaptation of the wall has been attained.

4.2 Microprocessor software

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The microprocessor system has the function to convert into analog values the wall contour data which are transmitted either by the process computer or are being input by the terminal. For that purpose 16 digital-analog converters are connected to the microprocessor bus. The program must control the input and output as well as assume the preparation of the wall contour data for the D/A-W.

For the preparation of the wall contour data we must first explain the following relationships:

The output signal of the displacement pickup lies in the range from -10V to +10V. The D/A-W is switched accordingly in order to attain the same voltage stroke. Figure 13 shows the displacement pickup voltage as a function of position.

For a position H_1 the displacement pickup generates a voltage $U_{\text{actual } 1}$. If this position is to be set, then the D/A-W must provide equally large voltage with reverse sign since

$$U_{\text{Motor}} = 0 \text{ if } U_{\text{should}} + U_{\text{actual}} = 0.$$

With the aid of figure 13 the following equation for the output voltage U_{actual} can be derived:

$$U_{\text{ist}} = \tan \varphi \cdot H - U_0$$

The slope tangent φ can be determined by a calibration of the displacement pickup. The D/A-W must provide the following voltage:

$$U_{\text{sol}} = -\tan \varphi \cdot H + U_0$$

Based on the coding of the D/A-W listed in table 1 we must find at its inlet the digital information

$$\text{DAC} = [-\tan \varphi \cdot H + U_0] \cdot F1$$

with

$$F1 = \frac{2048}{10V} = 204.8 \frac{1}{V}$$

$$\text{DAC} = -F1 \tan \varphi \cdot H + U_0 \cdot F1$$

$$\text{or } \text{DAC} = -F \cdot H + 0.2048 \cdot U_0 \cdot 10^3 \quad (5)$$

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The calculation of this equation is a part of the program REG2 described in the following. It processes the additional following tasks:

1. Input of the wall position by the terminal or by the process computer
2. Input of the values F and U_0
3. Lists of the wall position H , slope F and zero point U_0
4. Output of the wall position to D/A-W.

Figure 14 shows the program sequence of the program REG2. The program was written in such a way that the particular tasks can be fulfilled with a type of command input. The command can be found in the search- and jump table.

After the start of the program* a double dot appears as an answer signal; a command input can now follow.

The commands ST_n , OF_n , KO_n serve for the input resp. change of the values for positioning member height H , zero point displacement U_0 , and transmission factor F of the displacement pickup. An optional parameter is n ; it indicates the positioning member number. If it is not given, the value of 1 is used.

With the command LI we list for all 16 positioning members the positioning height, zero point, and transmission factor. The command AG carries out the calculation in accordance with equation 5 and relays the value to the D/A-W whereby the wall contour $H(x)$ is set immediately by the Servo-System.

A process computer coupling is possible with the PR command. This coupling is necessary if wall contour data are to be transferred from the process computer to the microprocessor. After the PR command has been given, the microprocessor continuously interrogates the terminal and the interface to the process computer (bit 0 of the output card) for a signal. If the process computer (bit 0 set) signals the output of wall contour data, the microprocessor confirms by means of a ready-announcement (bit 0 setting of the input card) its readiness to accept data.

The data are made ready by means of the output cycle of the process computer. The microprocessor interprets the output cycle as an interrupt and jumps into the interrupt program. The data are then acquired by it. At the same time an occupied-announcement is signalled to the process computer so that no additional data are sent. If the interrupt program has been processed, a return

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* Starting of programs is described in [9].

jump is made to the main program and the occupied-announcement is taken back. The process is continued until the wall positions have been transmitted for all 16 positioning members. When the transmission has been concluded, the wall contour, zero position, and transmission factors are listed similar to the case for the LI-command. If this wall contour is to be set, then a "CR" signal must be input by the terminal. Otherwise another arbitrary signal can be input. After that the microprocessor waits for renewed transmission by the process computer. By means of an additional "CR" signal one can jump out of the command "CR".

The SP-command serves to terminate the program REG2. After its input the monitor announces itself.

4.2.1 Expansion of the microprocessor software

At the beginning of chapter 3 it was mentioned that the microprocessor carries out control of the torque resp. motor current. This device is provided for the protection of the flexible walls and the motors against overloads. For this purpose it utilizes the nearly linear relation between torque and motor current. At the moment this device has not yet been installed; however, the software has been made ready as an operating plan. Figure 15 shows the required operating sequence:

The motor current of a motor is measured. If it is higher than the maximum value, an output line of the parallel input-output interface is set to 0 volts. In this way a continued processing (e.g. stopping of all motors) can take place. If the motor current should lie below the maximum current, the current is measured by the next motor. If all 16 motors have been checked, and if no excess current has been determined for any of them, an interrogation is made whether the sum of all motor currents (amount) is possibly equal to zero. If this is the case an announcement is given that the adjustment of the wall has been completed. After this the same control sequence starts anew.

This program is started about every 100 ms by a software-interrupt from an interval-time pickup. The motor current is measured with a digital voltmeter with series-connected multiplexer and Sample and Hold which are tuned specifically to the hardware of the microprocessor system are carried out.

4.3 Process computer software

Three tasks are essentially assigned to the process computer:

- calculation of the wall contours
- control of the pressure distribution measurement
- coordination of the control process.

For this 3 programs were developed which will be described in the following. However, for an understanding knowledge is necessary concerning the operating system, the process periphery, and their software. Detailed information concerning the running of the programs, the meaning of the variables, and the buildup of the data files can be found in the comments in the source programs.

4.3.1 Coordination program INTR

Figure 16 shows the sequence of the coordination program INTR. It is a peculiarity of this program that it is called up by a hardware interrupt. During the rest of the time it is placed into a waiting series. Thus the process computer is free for other tasks such as servicing other terminals of other users.

The program INTR is called up by the special process software (DEVSY, RTDEV)*. This first starts the program and enters its

* Description of the process hardware is supplied by the manufacturer of the process periphery.

program name (INTR) as well as the process periphery unit (1) into an interrupt list. The program INTR enters the test parameters of several plate files (subroutine EXT). After this the program obtains a stop signal which is formed by a subroutine callup of the process software (XDEV).

It is placed into a waiting condition and is not processed /19
further by the computer. A continuation of the program can only occur through an interrupt from the process periphery unit 1 (program Start-Scanner). This interrupt first starts a special program of the process software (RTDEV). It searches the interrupt list for entered programs for the unit 1. When the program name INTR has been found, the waiting program INTR is called up. It now operates further starting from the stop signal.

First there is a continuous measurement of the Mach number and an indication on the large display. The Mach number can be adjusted during this time. When the "measurement" button is pushed, the program branches into wall- and profile measurements for the upper side. The program MESS is started for each measurement. In the subroutine pressure the C_p and u/U_∞ values are calculated.

When the upper side has been measured, the program (EXINT) is called up to calculate the upper wall contour. During this time the program INTR continues to run and starts the measurement of the pressures on the under side.

During the measurement the program EXINT ends and records the result on a plate file (TEMPFI). After the measurement on the under side has been completed, the program EXINT is again started which now calculates the lower wall contour. In this case the program INTR waits for completion of EXINT. After the lower wall contour has been calculated, the wall contour is given to the waiting microprocessor. The output sequence is similar to the process

computer-coupling described under microprocessor software.

The program INTR can now be called off by the process software DEVSY so that it is cancelled from the interrupt list. Otherwise the program is again placed into a waiting state and can be started anew by a hardware interrupt. Figure 17 shows the time sequence of the 3 programs. In addition the sequence of the programs with the mutual data exchange is shown in figure 18.

4.3.2 Test program MESS

/20

The program MESS allows the measurement of electrical voltages on the inlet channels 0 and 1 of the multiplexer with the aid of an A/D-W. For this the apparatuses must be plugged into the process periphery unit 1 (slot 3: A/D-W, slot 4: multiplexer with Sample and Hold). Beyond that the program initiates the continuation of the switching of the scanivalves via the output card in slot 2. The program can only be called up by other programs through the EXEC calls*. During the call-up 5 parameters can be transmitted of which, however, only one is required here:

1. - 4. -
5. pause time in ms · 10

After the call-up the program first places itself into the waiting state for the duration of the pause time. This pause serves to equalize the time constant of the pneumatic system (pressure hoses, air chamber in the scanivalves etc.). Then follows the measurement of the voltage in mV for the channels 0 and 1. Finally the continuation of the switching of the scanivalves is initiated and the measured values are transmitted by means of an EXEC call to the calling program (e.g.:INTR).

* See also RTE-IV Programmer's Reference Manual [11].

4.3.3 Computer program EXINT

The wall contours are calculated by means of the program EXINT. It calculates a wall contour per program sequence. The start and the data transmission result from EXEC calls of the calling program INTR. A parameter transmission during call-up controls the sequence of the program:

1. length of the data transmission-memory in words
2. number of the first u/U_∞ value
3. number of the last u/U_∞ value
4. upper-/under side calculation
5. --

To 1) The part of the common block of the program INTR is made available to the program EXINT. These are the field ranges resp. variables: /21

X, U, UT, XHY, H, NWHU, NWHO, IWANU, IWANO, REFA

Their meaning can be seen from the commentary of the source programs.

The length of the data transmission memory is calculated in accordance with the following relation:

length = number of the real variables · 2 + no. of the
integer variables

To 2) The numbering of the pressure-measurement holes in the
and 3) walls and thus also the indexing of the measured values
are made in the flow direction starting with the upper wall:

pressure holes upper: 1 to 23
pressure holes lower: 24 to 46

From this it follows for the upper wall that the index number of the first u/U_∞ value is 1 and that of the last one 23. Correspondingly the numbers for the lower wall are 24 and 46.

To 4) The calculation of the upper wall contour requires a 1, the calculation of the lower value a 2 as transmission value.

The program EXINT first starts with the calculation of the estimated values in accordance with the control algorithm equation 1 for one wall. With these estimated values the velocity distribution of the v-components in the subroutine VSTOR is calculated. The wall contour is calculated in the subroutine HKONT. The results are passed on to the printer resp. can, in order to guarantee a faster memory storage, be recorded via the spooler on a plate file. The results are transmitted to the calling program (INTR) in two ways:

During the calculation of the upper wall contour (5. parameter = 1) the results (part of the common block, figure 18) are recorded on a plate file (TEMPFI) which is read off at the appropriate time by the calling program. /22

During the calculation of the lower wall contour (5. parameter = 2) the results are passed on by an EXEC call to the calling program.

5. SUMMARY /23

The control device for the adaptive tunnel at the TU Berlin presented here has been in operation for one-half year. A series of profile investigations (CAST 7, NACA 0012) have already been conducted with it. Here we found a considerable reduction of the test times compared to those of earlier investigation with manual adjustment of the walls and value inputs into the computer. For a given test case the adjustment to an adaptive wall shape takes, as an example, 1 to 2 minutes. A reason for this short

control time can be found in the fast calculation of the wall contour which is determined by the computer type used and the optimization of the computer program. An additional reason can be found in the high adjusting speed of the flexible walls. A different measuring method for acquiring the wall pressure distribution would produce even greater reductions of the control time. Thus the use of an electronic multiple pressure measuring position switch would bring about a reduction of the measuring time from a present value of 50% of the test time to 1%.

The adjusting accuracy of the Servo-System was considered to be entirely adequate during the profile investigations. On the other hand, the calculation method of the wall contour in the transsonic Mach number range is in need of expansion. As a first requirement boundary layer effects must be taken into account.

The successful testing of the control device described here as well as its limited hardware expenditures for the adaptive wind tunnel must be evaluated as essential prerequisites for the carrying-over of this test technique to other, larger wind tunnels.

6. REFERENCES

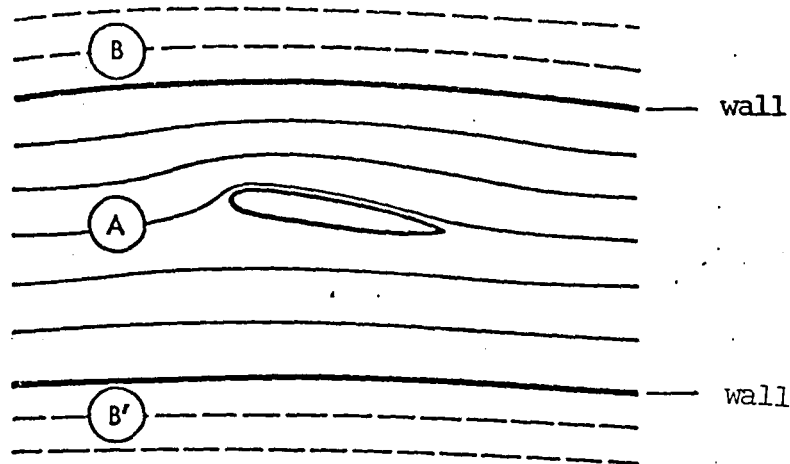
/24

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FIGURES AND TABLES

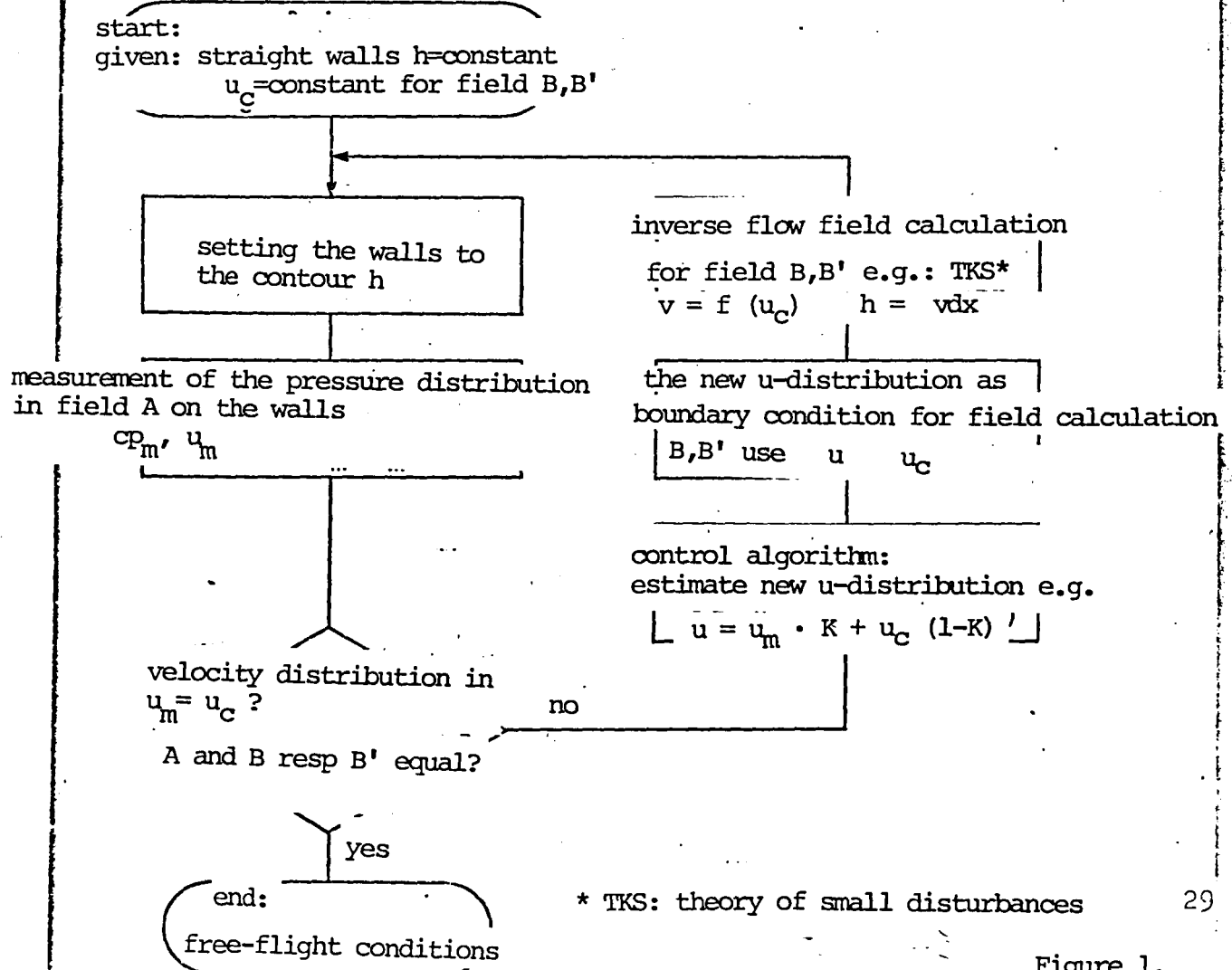
Table 1 Coding of the digital/analog converter

D/A-W outlet voltage	input information	
	12 bit	
	hexidecimal	decimal
- 10 V	800	-2048
- 9.9951 V	801	-2047
0V	000	0
+ 0.00488 V	001	1
+ 9.9951 V	7FF	2047



A internal field, actually existing flow

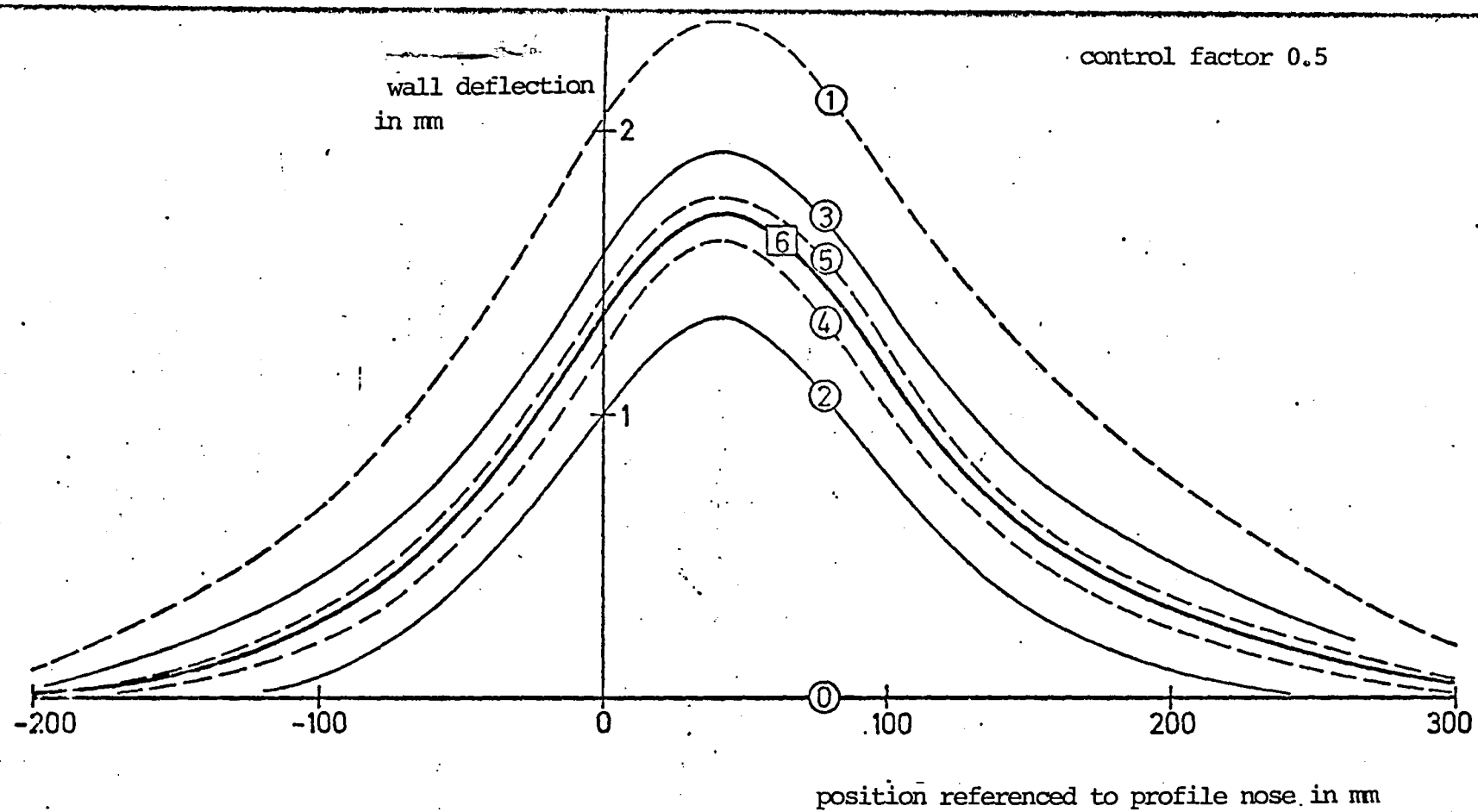
B,B' fictitious outer field, imagined flow with wall contour as boundary condition



* TKS: theory of small disturbances

29

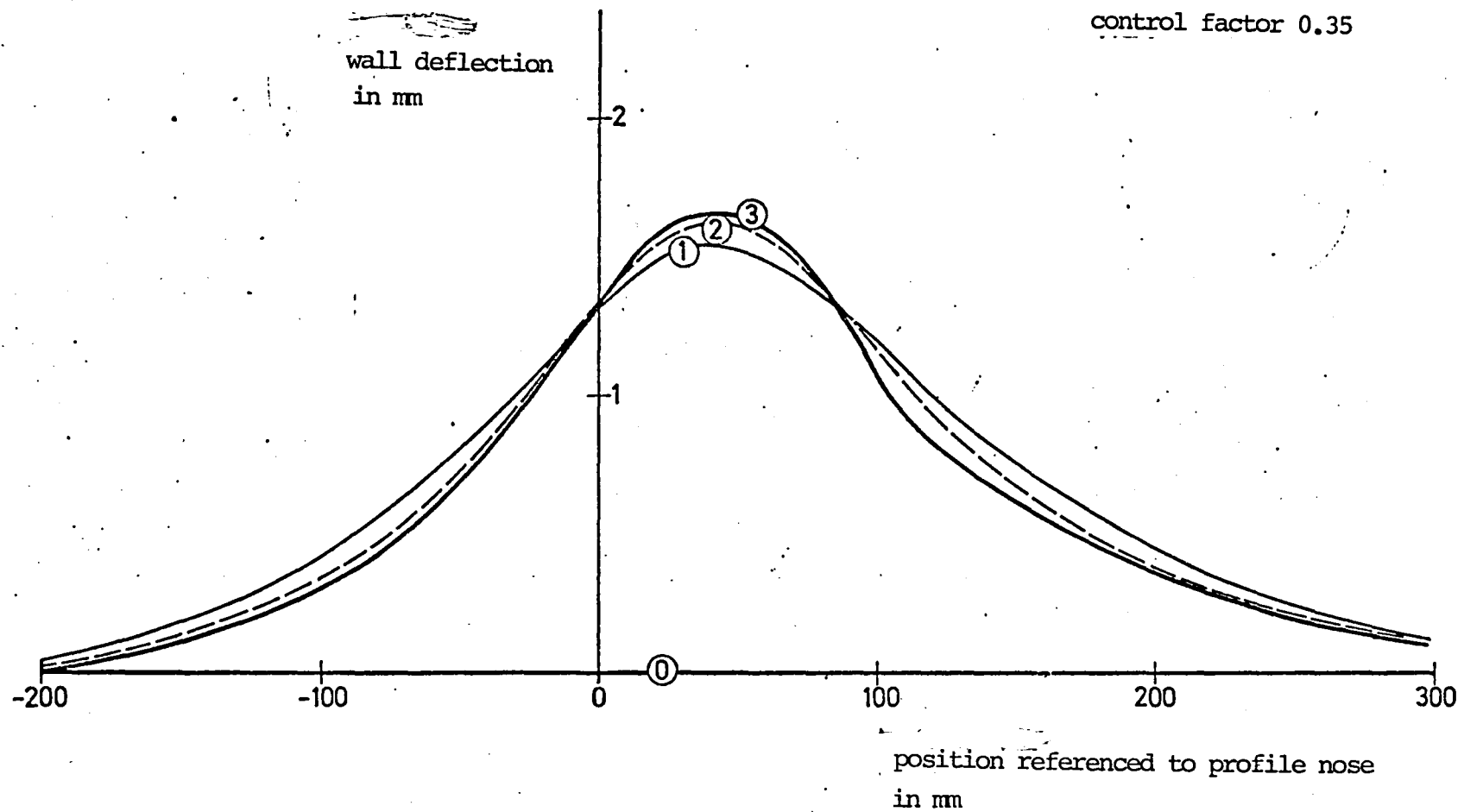
Figure 1.



Computer simulation of the control !

6 control steps

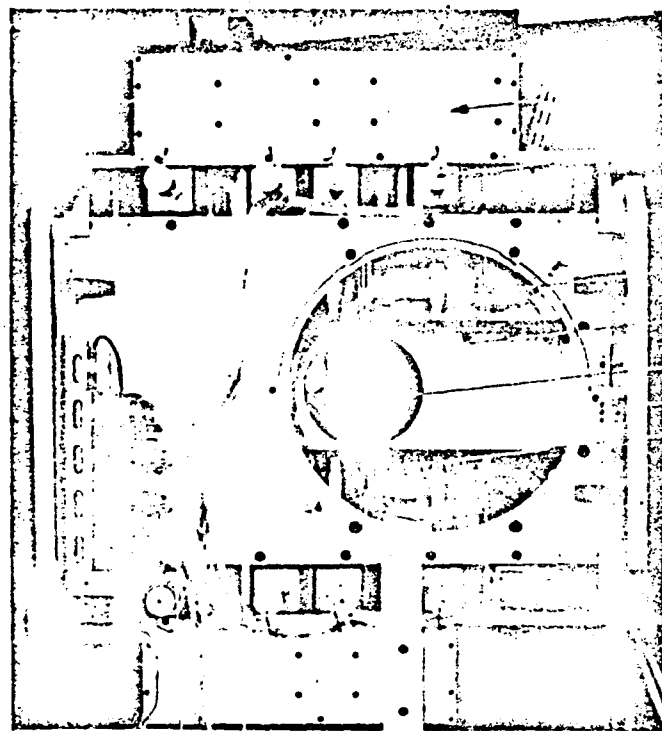
Figure 2



Computer simulation of the control

3 control steps

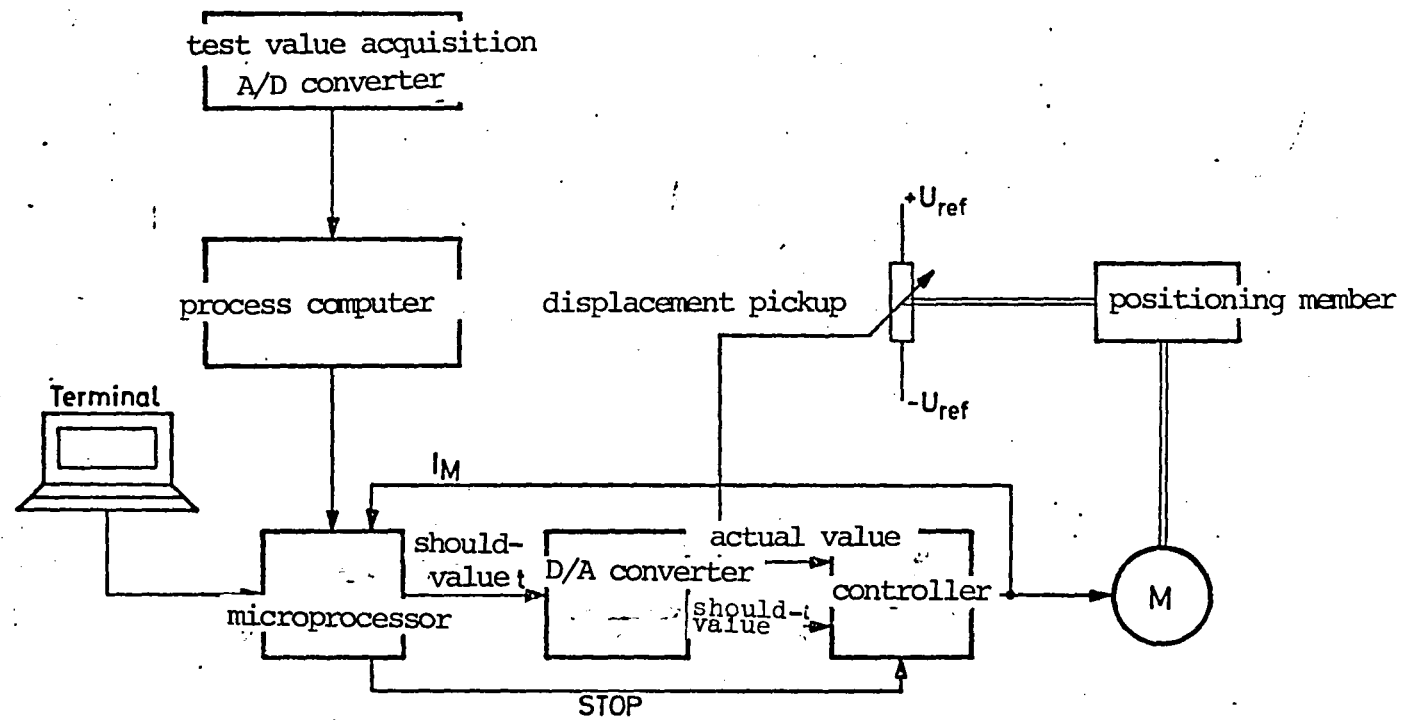
Figure 3



- 8 displacement pickups
- electric motor
- positioning member
- flexible wall
- profile support
- wall pressure-pickup holes

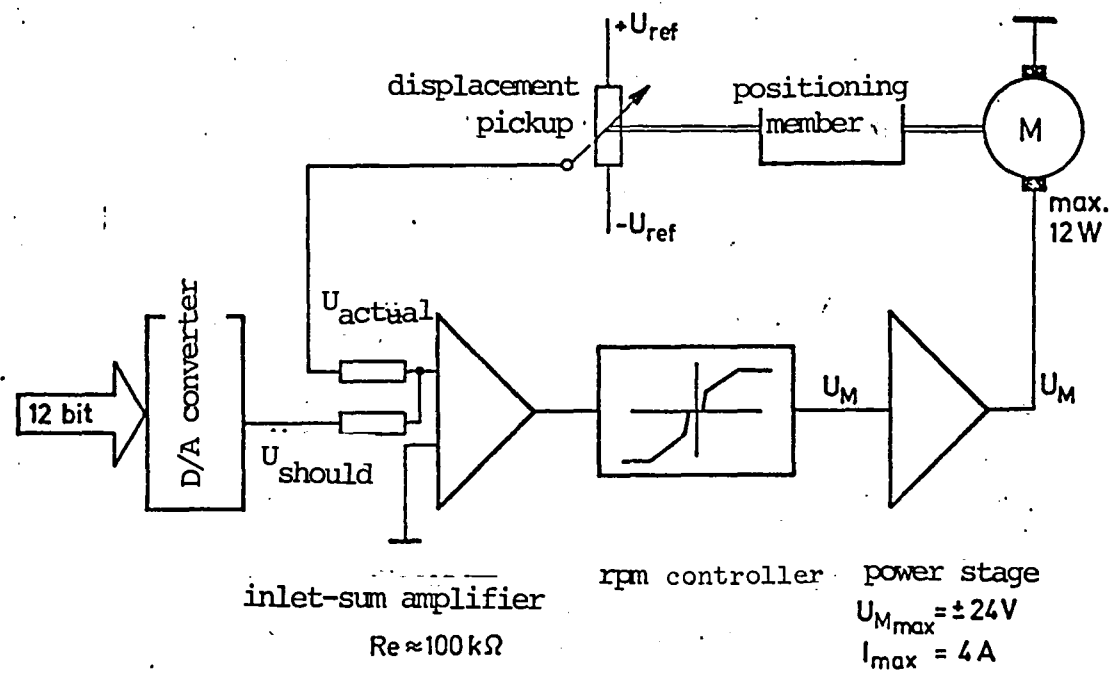
Test section of the adaptive wind tunnel

Figure 4



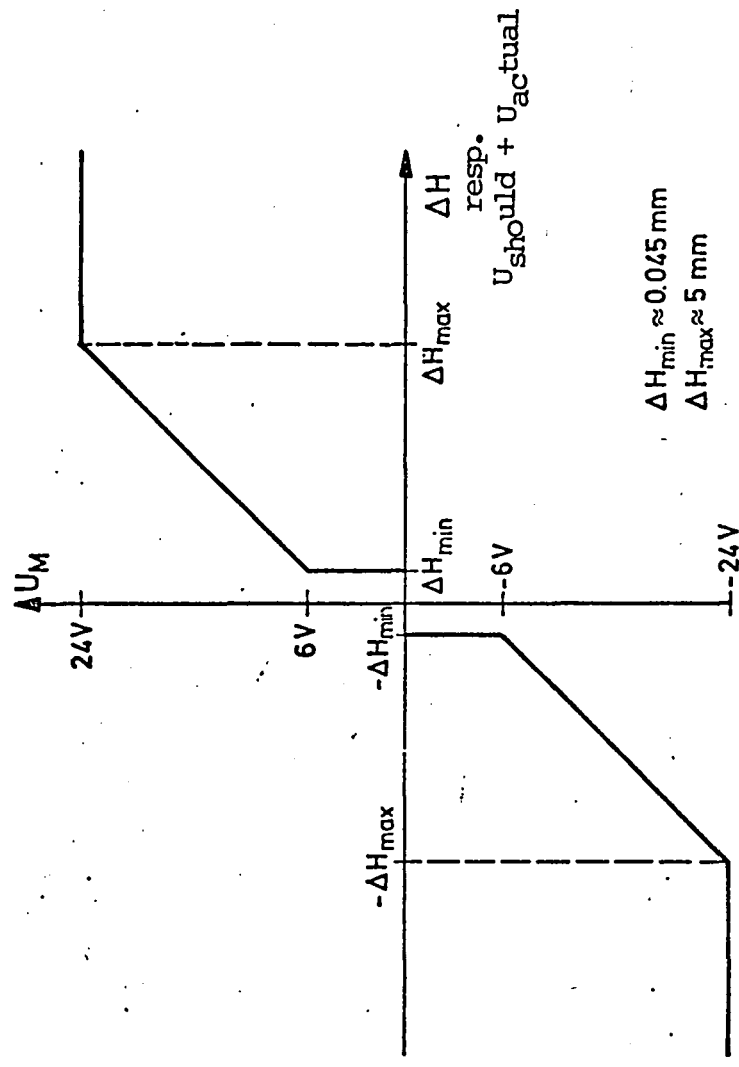
Block diagram of the test installation: adaptive wind tunnel

Figure 5.



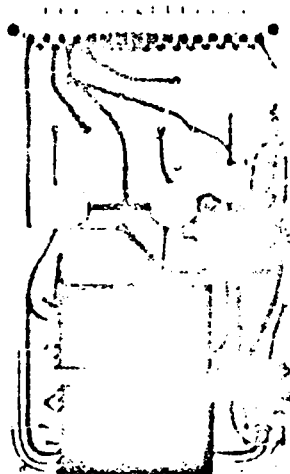
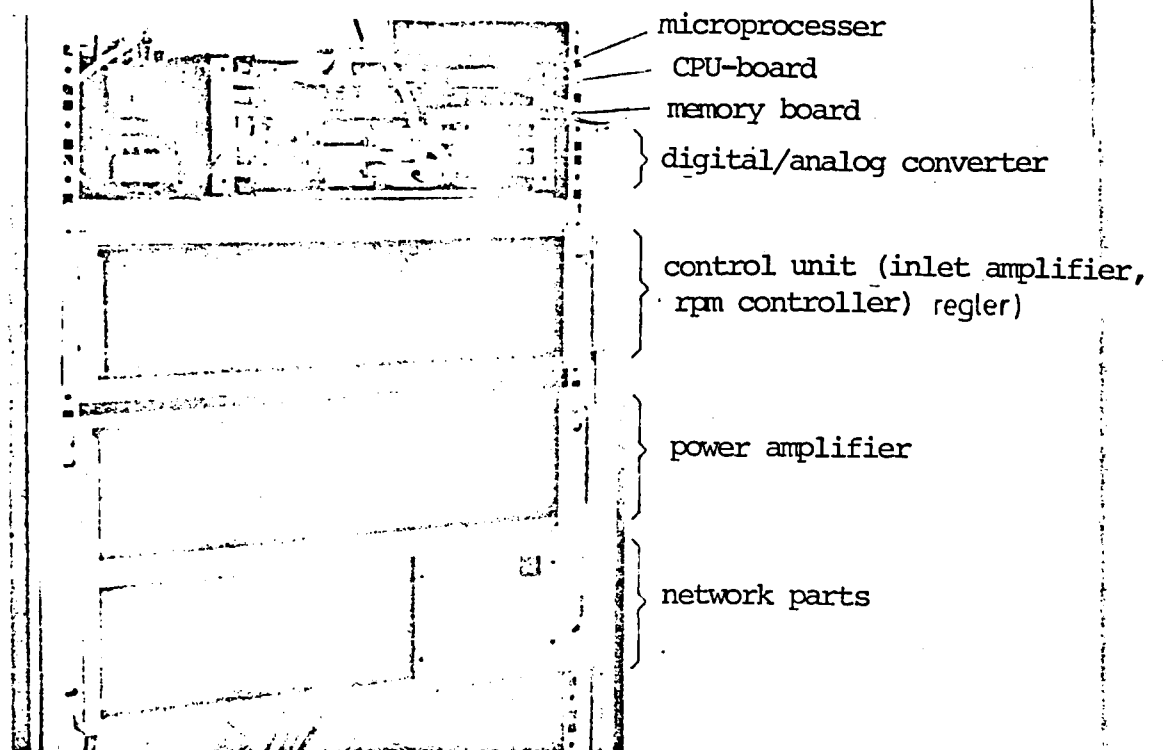
Block diagram of the servo-system

Figure 6

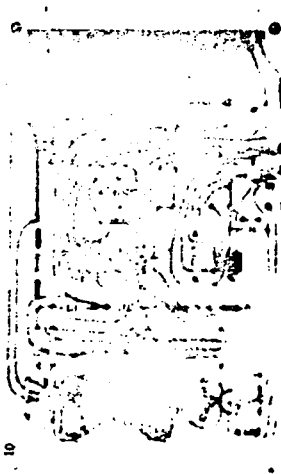


Characteristic line of the rpm controller

Figure 7



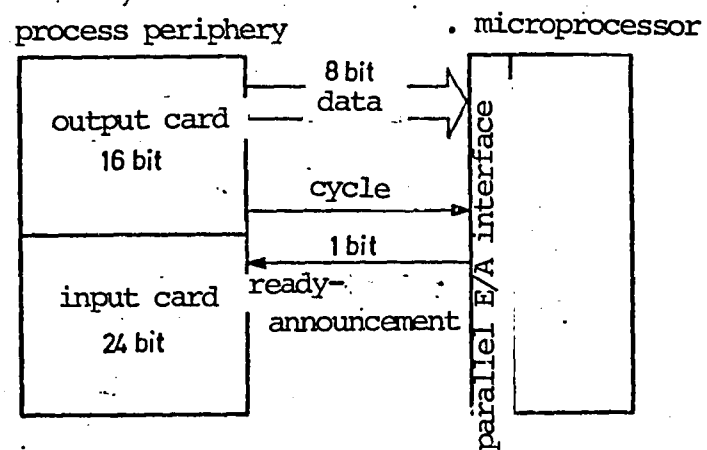
power amplifier



control card

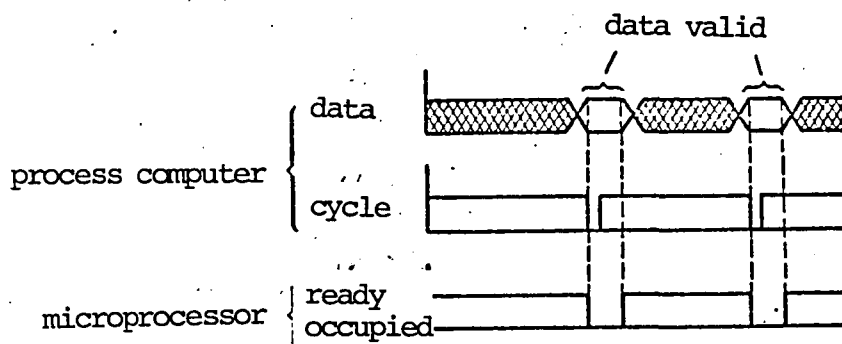
Electronics of the servo-system

Figure 8



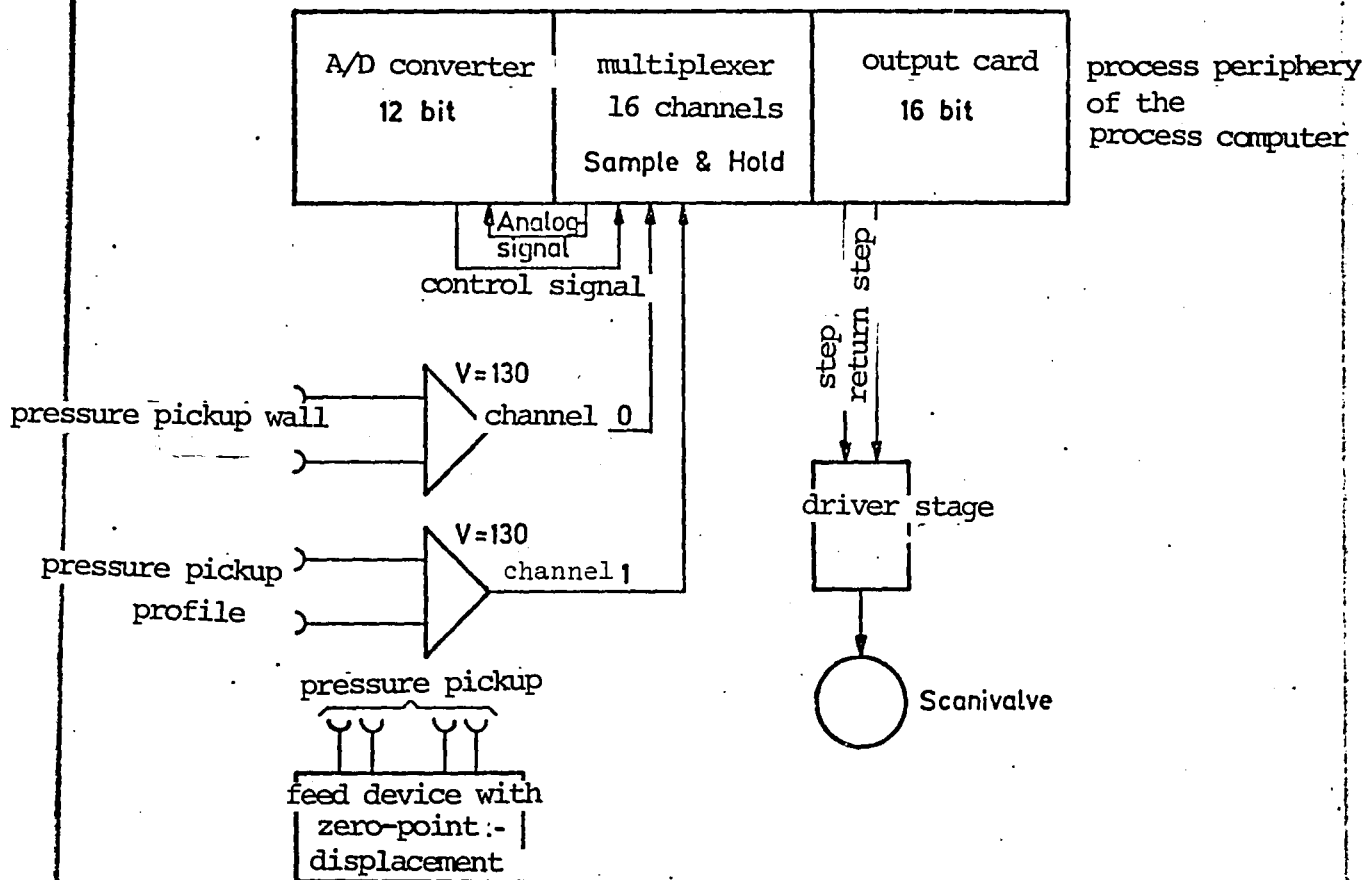
Process computer-microprocessor coupling

Figure 9



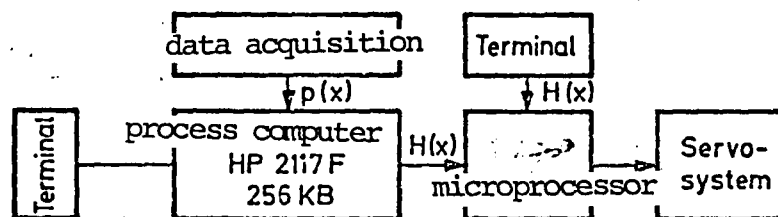
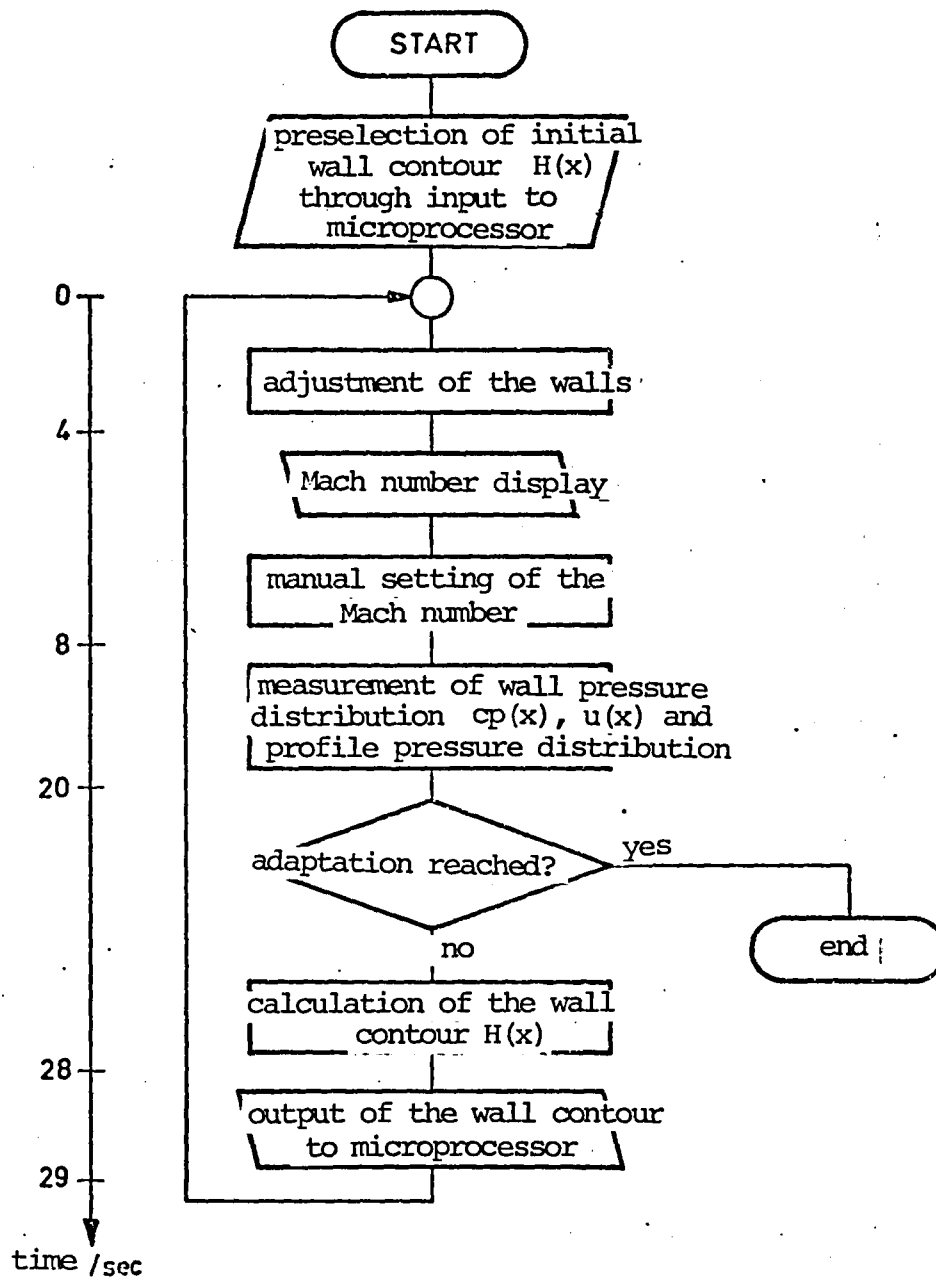
Signal flow diagram of the data transmission from process computer-
microprocessor

Figure 10



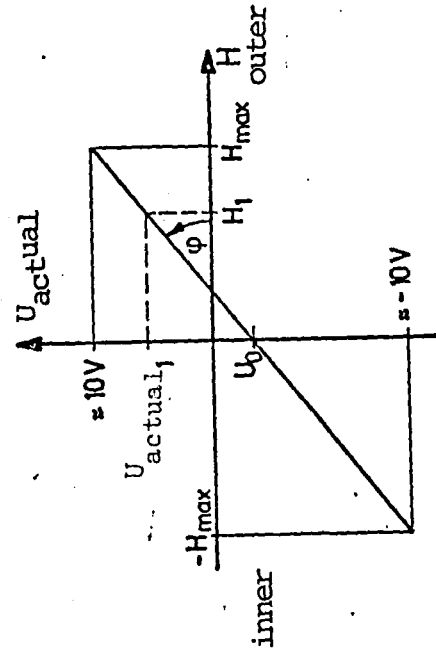
Measured value acquisition

Figure 11



Control sequence plan

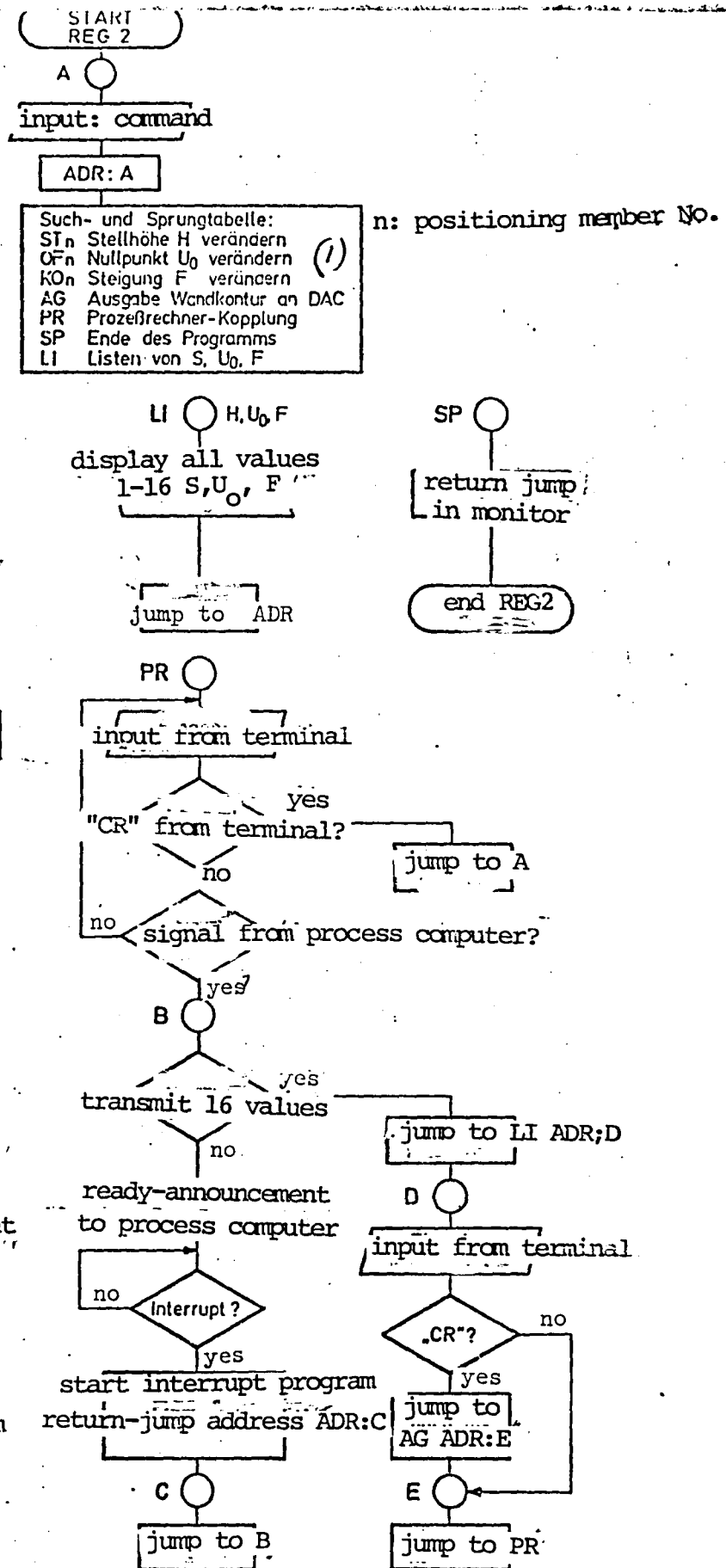
Figure 12



Displacement-pickup output signal

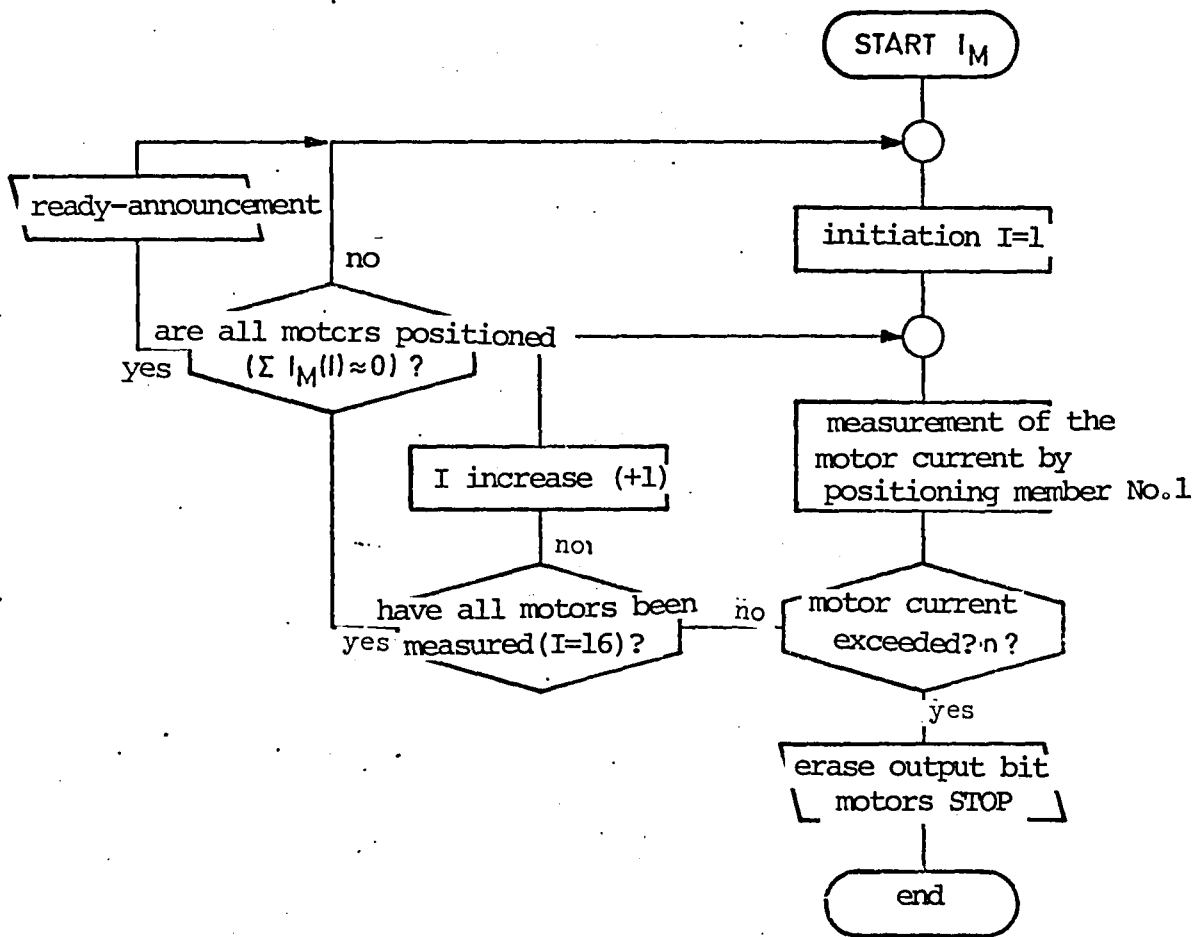
Figure 13

- (1) search- and jump table:
 ST n change position height H
 OF n change zero point U_0
 KO n change slope F
 AG output wall contour to DAC
 PR process computer coupling
 SP end of the program
 LI listing of S, U_0 , F



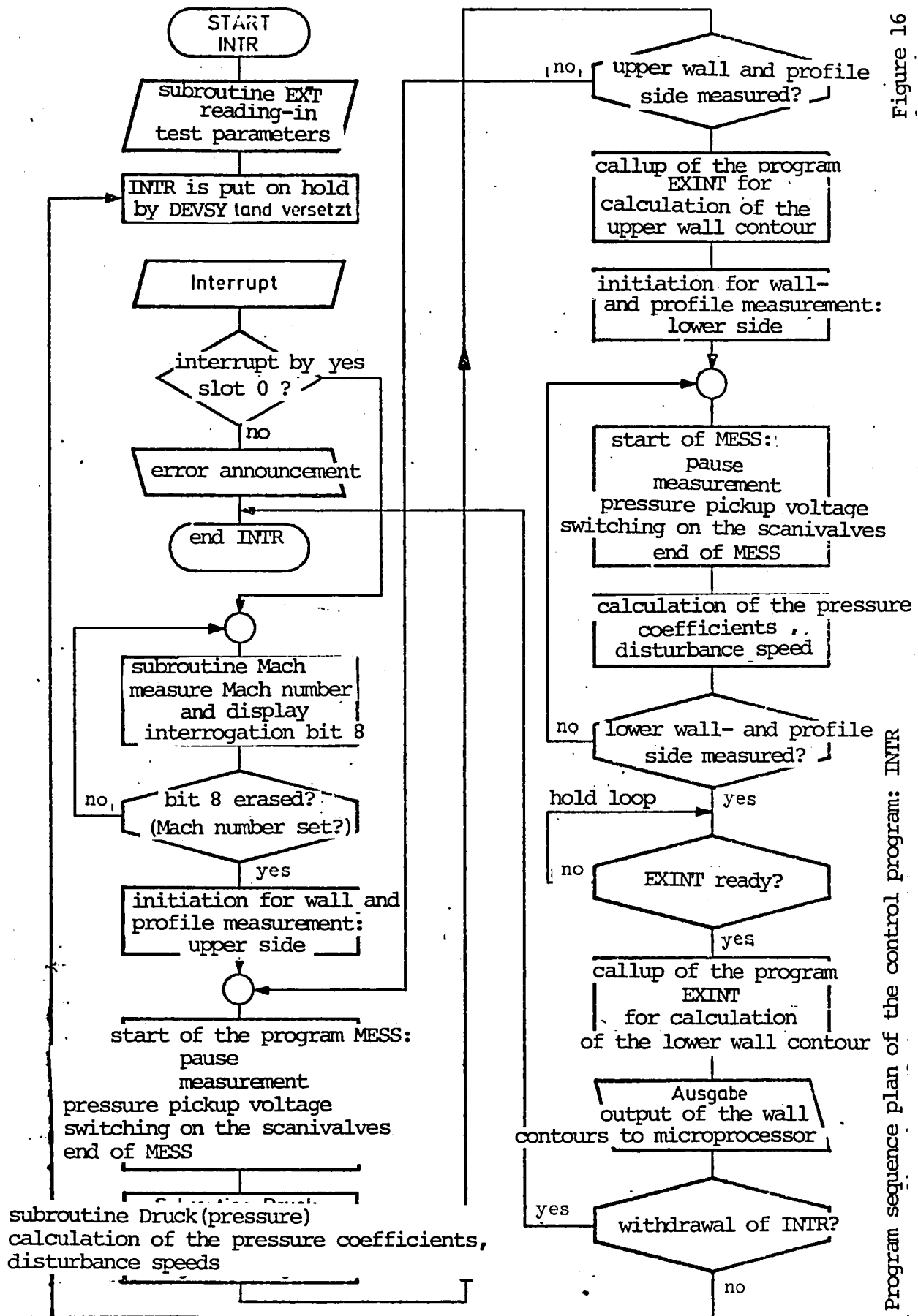
Program sequence of the microprocessor program REG2

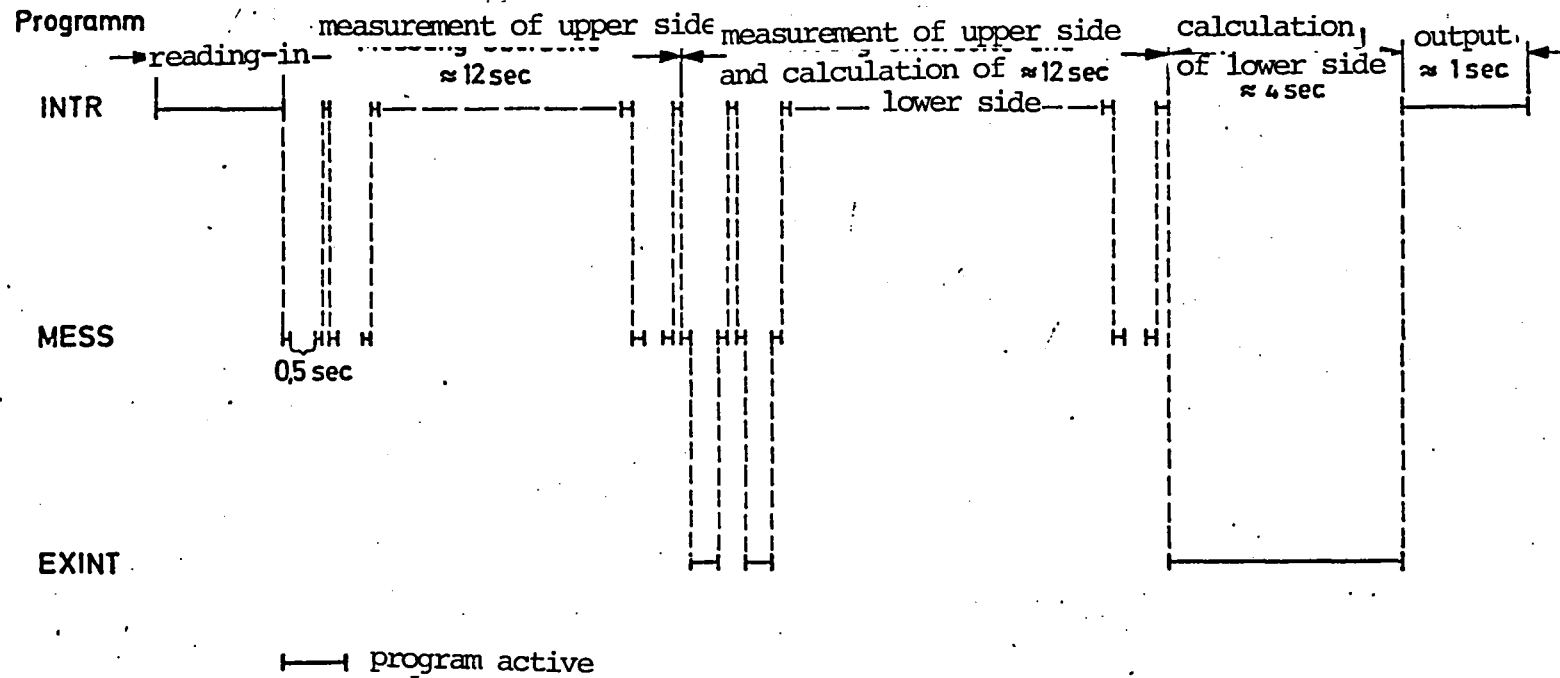
Figure 14



Torque control

Figure 15





Time sequence of the three programs for the process: adaptive wind tunnel

Figure 17.

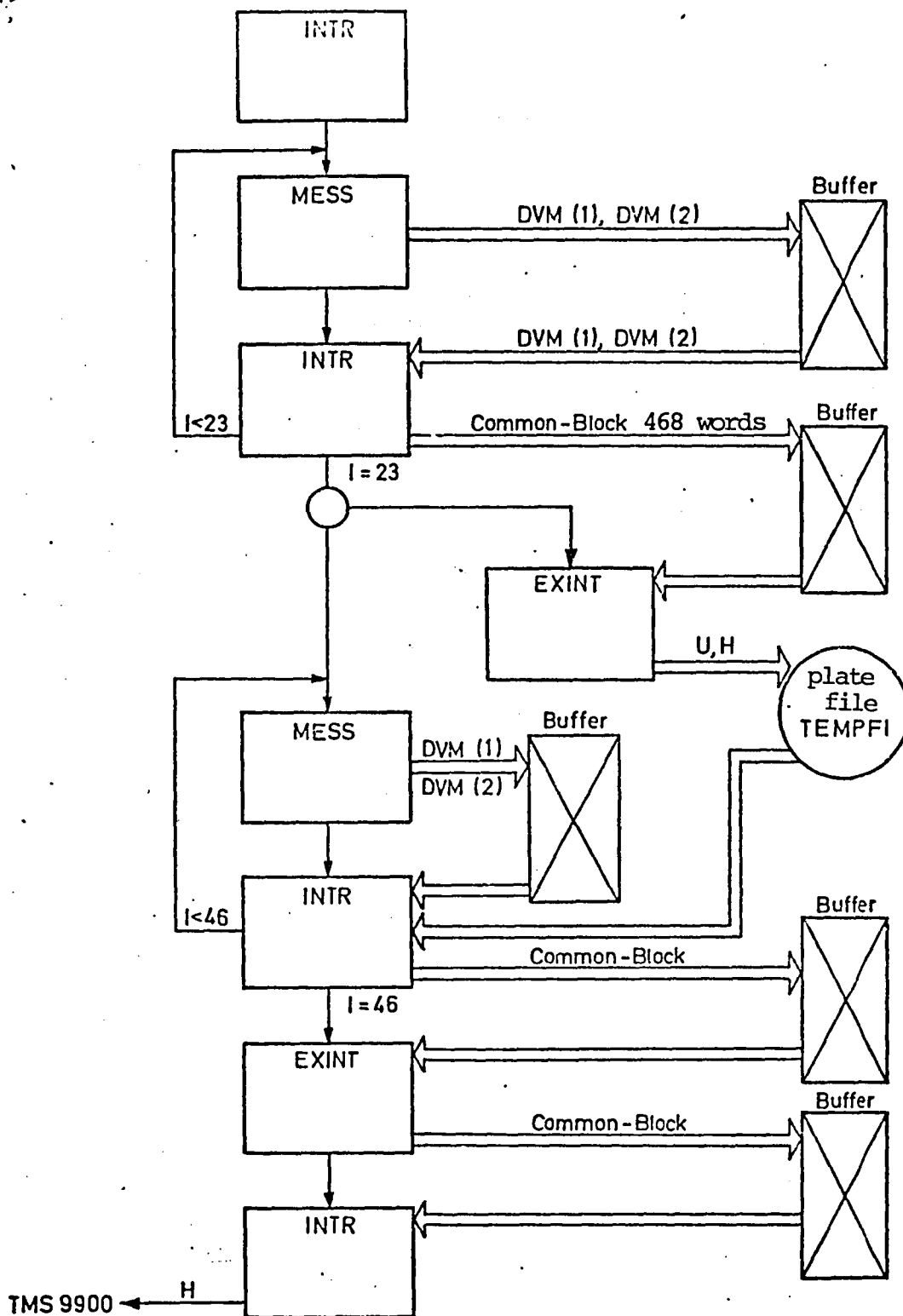


Figure 18 Data transmission - Organization of the three programs for the process: adaptive wind tunnel

APPENDIX

Technical data for the individual systems of the electronic control device

A-1

1. Servo-System

1.1 Direct current motor with permanent magnetic field

rated power	12 W
starting moment M_{an}	8.83 Ncm
rated torque M	1.91 Ncm
rated rpm	6000 min ⁻¹
power pickup	24 W
type of operation	100% ED
rated voltage	24 V

1.2 Spur gear drive, displacement spindle

gear reduction	1 : 106
maximum torque	300 Ncm
spindle	M 10 x 1

1.3 Displacement pickup, potentiometric

total resistance	2 K Ω
non-linearity	0.2%
resolution	0.08 mm
available lift	± 25 mm
resistance material	chrome-nickel-wire

1.4 Control part - power amplifier - electronics

maximum outlet current	4 A
minimum outlet voltage	6 V
maximum outlet voltage	24 V
switch threshold	22 mV
limit device onset	1.1 V

dead range	44 mV
displacement pickup feed	± 12.5 V
transmission factor displacement	32 mV/0.08 mm = 400
pickup* layout value	
voltage supply control part	± 20 V
voltage supply power section	± 30 V

2. Microprocessor system

2.1 Microprocessor TMS 9900 (Texas Instrument Inc)

data bus width	16 bit
memory size	5 KB
system cycle	3 MHz
input/output	2 x in series
interfaces	1 x parallel 16 bit with 16 interrupt lines cassette interface (KCS-code)

2.2 Digital-/analog converter

resolution	12 bit
calibration	4.8828125 mV/LSB
input information via DMA	2' complement
output	± 5 mA / ± 10 V
non-linearity	± 0.01 %

3. Process computer

3.1 Central unit (HP 2117 F)

data bus width	16 bit
memory size	256 KB
operating system	Real-Time-Execute (RTE IV)
plate size	2 x 9.8 MB

* see also Table A 1

3.2 Process periphery (DEV-system)

Slot 0 input card	24 bit with interrupt
Slot 2 output card	16 bit
Slot 3 analog/digital converter	
resolution	12 bit
inlet range	± 5 V
switching	single ended
	2' complement
conversion time	8 μ s
Slot 4 multiplexer with Sample and Hold	
no. of channels	16
accuracy	12 bit

4. Measuring device

4.1 Pressure pickup

pressure range	± 1013 mbar
outlet voltage max. at	± 30 mV
10 V feed	

4.2 Amplifier, galvanic separation

gain	130
inlet range maximum	± 1 V
outlet max.	± 20 mA
shunt resistance	300
frequency range	0 to 10 Hz

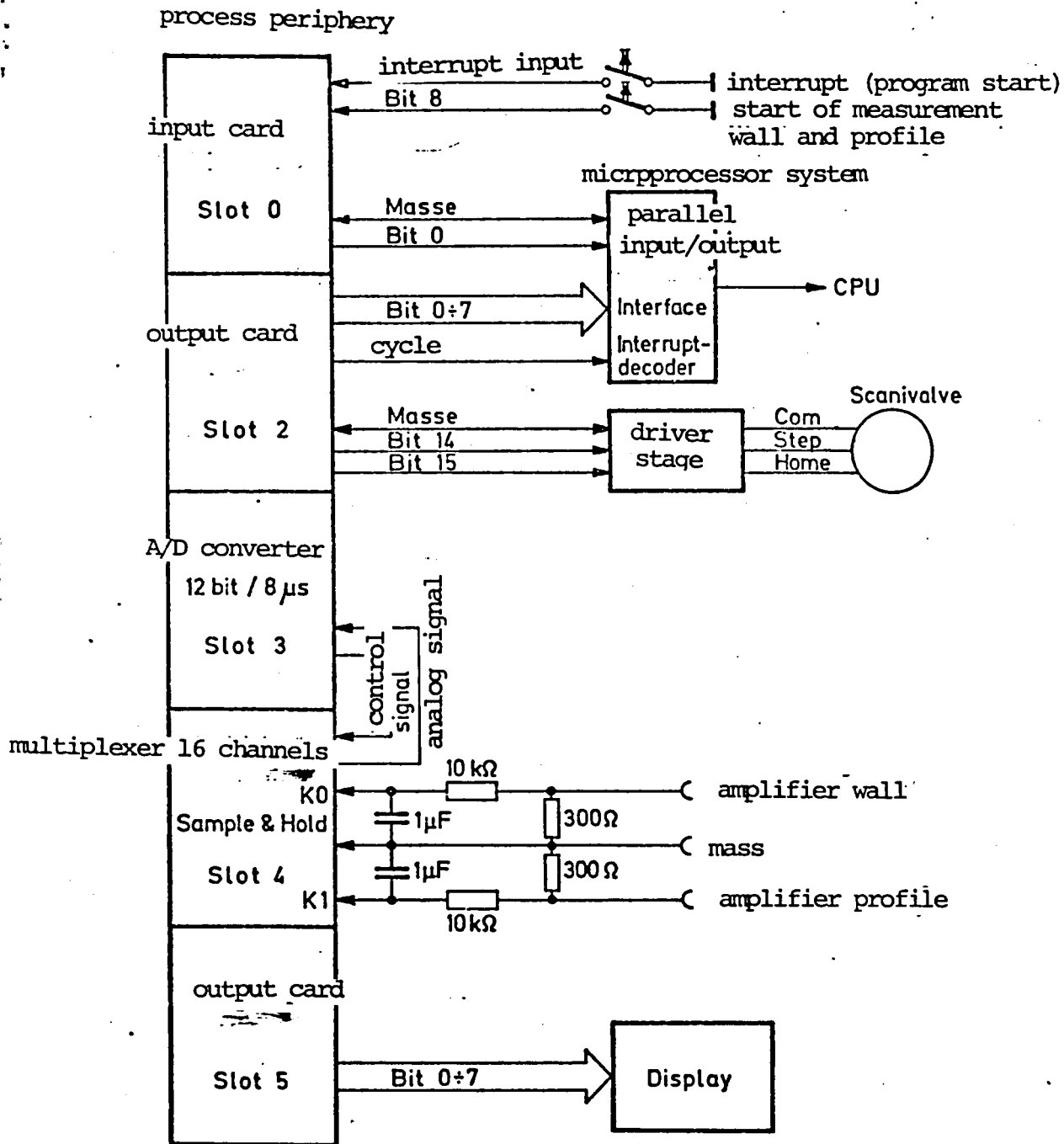
4.3 Driver stage

inlets	1 TTL-Last
outlets	24 V/ 4A
return pulse duration	2.5 sec
step pulse duration	50 ms

Table A 1 Displacement pickup - data

/A-4

Positioning member No.	max. lift/mm	U _o /mV for straight walls	calibration factor F	transmission factor mV/mm tan ϕ	
1	5.18	-1120	330.89	1615.67	above
2	51.16	-1348	86.25	421.17	
3	51.56	- 795	92.47	451.5	
4	51.16	- 773	89.84	438.67	
5	51.05	-1500	88.75	433.33	
6	51.26	- 214	96.46	471.00	
7	51.26	-1502	87.07	425.17	
8	51.66	- 494	90.28	440.83	
9	51.21	- 538	90.04	439.67	below
10	51.31	-1558	86.97	424.67	
11	51.16	- 965	89.63	437.67	
12	51.31	-1355	87.14	425.50	
13	51.10	-1690	82.94	405.00	
14	51.05	- 746	92.77	453.00	
15	51.16	- 866	88.00	429.67	
16	5.20	-3417	323.86	1581.33	



Summary of the entire hardware buildup

Terminal Plan for the Hardware Buildup

/A-6

Apparatus designation	meaning	terminal	terminal	meaning	apparatus designation
input card	bit 0	A	20	outlet P0.	plug P4*
"	bit 8	1		start of the meas.	remote control
"	interrupt	S		program start	"
"	mass	15		mass	"
output card	ready-announce-ment	S	8	Interrupt INT5	P4*
"	bit 7	J	40	high-bit P15	P4*
"	bit 6	H	38	P14	P4*
"	bit 5	F	36	P13	P4*
"	bit 4	E	34	P12	P4*
"	bit 3	D	32	P11	P4*
"	bit 2	C	30	P10	P4*
"	bit 1	B	28	P 9	P4*
"	bit 0	A	26	low-bit P 8	P4*
"	mass	14;15	9 to 39	mass	P4*
"	bit 14	7		step	{driver stage
"	bit 15	8		return step	{scanivalve
multiplexer S & H	channel 0	C	4	wall press. pickup	apparatus plug
	channel 1	3	6	profile pressure pickup	"
	mass	10	16/18	mass	"
	analog from	N	L	analog in	A/D converter
	control signal	13	H	control signal	"

* microprocessor

End of Document